Salicylic acid enhances antioxidant capacity and improves growth and yield of okra (*Abelmoschus esculentus* cv. Red Balady)

Sabry M. Youssef[1], Antonio López-Orenes[2], María A. Ferrer[2]*, Antonio A. Calderón[2]

[1]Horticulture Dept., Faculty of Agriculture, University of Ain Shams, Egypt

[2] Departmento de Ingeniería Agronómica, Universidad Politécnica de Cartagena, Paseo Alfonso XIII 48, 30203 Cartagena (Murcia), Spain

*Corresponding author:

Telephone: 34 968 325535; e-mail: mangeles.ferrer@upct.es

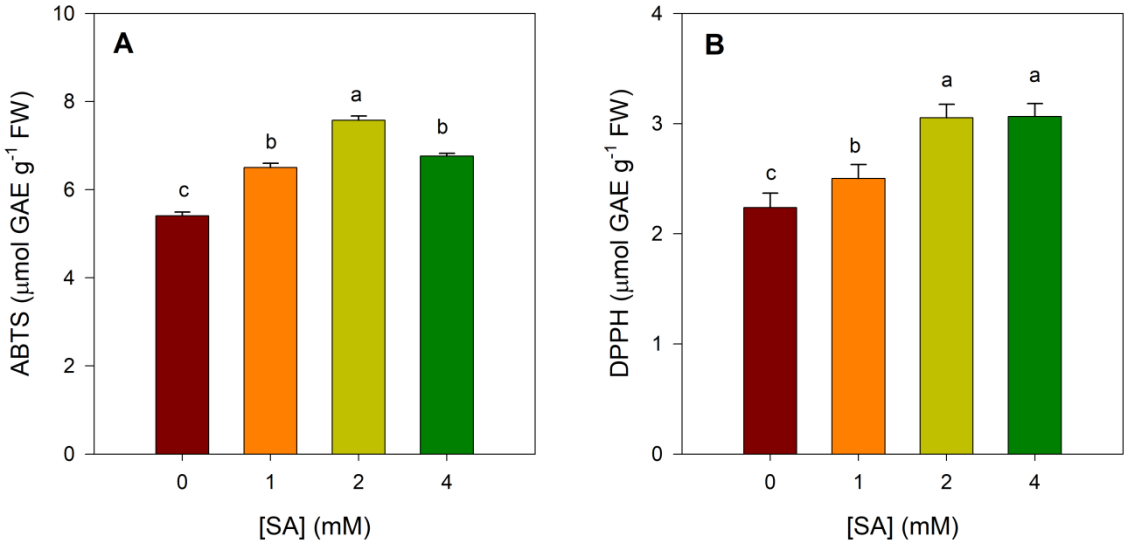

Figure S1. Effect of foliar SA applications on total antioxidant activities in leaves of 45-d-old okra plants using gallic acid as standard. A, $ABTS^{\bullet+}$- radical scavenging activity; B, $DPPH^{\bullet}$-radical scavenging activity. *F*-values and level of significance from ANOVA: ABTS, 107.95***; and DPPH, 50.02*** (*** $P \leq 0.001$).

Table S1. Pearson's correlation coefficients among biochemical data measured in leaves of 45-d-old okra plants. Statistical significance was represented as asterisks (*$P \leq 0.05$; **$P \leq 0.01$).

	chla	chlb	ABTS GAE	ABTS TE	DPPH GAE	DPPH TE	FRAP	HCAs	TFC	FLAVAN	TPC	Pro	Protein	PAL	PRX	MDA	SA
chla	1	.952**	.618**	.618**	.677**	.677**	.759**	.737**	.728**	.656**	.599**	.504**	.621**	0.253	0.297	-.389*	.812**
chlb	.952**	1	.633**	.633**	.678**	.678**	.784**	.701**	.685**	.728**	.607**	.521**	.708**	0.294	0.347	-.398*	.836**
ABTS-G	.618**	.633**	1	1.000**	.775**	.775**	.872**	.546**	.480**	.621**	.759**	.864**	.740**	.768**	.531**	-.822**	.821**
ABTS-T	.618**	.633**	1.000**	1	.775**	.775**	.872**	.546**	.480**	.621**	.759**	.864**	.740**	.768**	.531**	-.822**	.821**
DPPH-G	.677**	.678**	.775**	.775**	1	1.000**	.861**	.780**	.760**	.636**	.791**	.812**	.713**	.609**	0.246	-.726**	.828**
DPPH-T	.677**	.678**	.775**	.775**	1.000**	1	.861**	.780**	.760**	.636**	.791**	.812**	.713**	.609**	0.246	-.726**	.828**
FRAP	.759**	.784**	.872**	.872**	.861**	.861**	1	.828**	.777**	.727**	.819**	.822**	.712**	.607**	.472**	-.746**	.951**
HCAs	.737**	.701**	.546**	.546**	.780**	.780**	.828**	1	.974**	.665**	.680**	.542**	.440*	0.199	0.236	-.491**	.855**
TFC	.728**	.685**	.480**	.480**	.760**	.760**	.777**	.974**	1	.619**	.649**	.484**	.421*	0.141	0.165	-.408*	.809**
FLAVAN	.656**	.728**	.621**	.621**	.636**	.636**	.727**	.665**	.619**	1	.571**	.506**	.526**	0.327	.529**	-.478**	.805**
TPC	.599**	.607**	.759**	.759**	.791**	.791**	.819**	.680**	.649**	.571**	1	.763**	.493**	.599**	.365*	-.733**	.751**
Pro	.504**	.521**	.864**	.864**	.812**	.812**	.822**	.542**	.484**	.506**	.763**	1	.714**	.920**	0.269	-.915**	.673**
Protein	.621**	.708**	.740**	.740**	.713**	.713**	.712**	.440*	.421*	.526**	.493**	.714**	1	.630**	0.230	-.556**	.674**
PAL	0.253	0.294	.768**	.768**	.609**	.609**	.607**	0.199	0.141	0.327	.599**	.920**	.630**	1	0.273	-.868**	.432*
PRX	0.297	0.347	.531**	.531**	0.246	0.246	.472**	0.236	0.165	.529**	.365*	0.269	0.230	0.273	1	-0.320	.571**
MDA	-.389*	-.398*	-.822**	-.822**	-.726**	-.726**	-.746**	-.491**	-.408*	-.478**	-.733**	-.915**	-.556**	-.868**	-0.320	1	-.631**
SA	.812**	.836**	.821**	.821**	.828**	.828**	.951**	.855**	.809**	.805**	.751**	.673**	.674**	.432*	.571**	-.631**	1

Table S2. Effect of foliar SA applications on agronomic vegetative growth parameters as well as fruit yield-related attributes. The data are means ± SE from n= 60 from two field experiments carried out on two different growing seasons. Different letters in the same row indicate significant difference at $P \leq 0.05$ (Tukey's HSD post-hoc test). Results of one-way ANOVA test showing F-values and level of significance for selected yield parameters are also indicated. Level of significance: ***$P \leq 0.001$; NS = not significant.

	SA treatments				*F*-values
	Control	**1 mM**	**2 mM**	**4 mM**	
Vegetative growth parameters					
Plant height (cm)	89.02 ± 0.71d	93.74 ± 0.71c	105.62 ± 1.23a	97.41 ± 0.75b	127.52***
Nº branches	2.53 ± 0.09c	3.23 ± 0.09b	3.77 ± 0.09a	3.22 ± 0.10b	59.70***
Stem girth (cm)	2.37 ± 0.03a	2.34 ± 0.03a	2.37 ± 0.03a	2.31 ± 0.03a	2.04^{NS}
Nº leaves	37.25 ± 0.32d	40.77 ± 0.40c	52.92 ± 0.63a	45.02 ± 0.39b	452.78***
Leaf area (cm^2)	240.07 ± 1.49b	241.60± 1.20b	247.10 ± 0.80a	242.00 ± 0.81b	15.07***
Leaf relative water content (%)	75.32 ± 0.18c	76.79 ± 0.16b	81.02 ± 0.24a	77.61 ± 0.21b	142.87***
Membrane Stability Index (%)	73.41 ± 0.25c	75.84 ± 0.23b	87.68± 0.25a	72.60 ± 0.23c	1711.73***
Fresh vegetative growth (g)	762.14 ± 6.62d	834.09 ± 8.12c	1082.68±12.84a	923.43 ± 9.14b	452.78***
Dry vegetative growth (g	118.60 ± 1.88d	127.86 ± 2.18c	162.83 ± 2.28a	137.86 ± 1.64b	182.77***
N (%)	2.96 ± 0.03c	3.19 ± 0.04b	3.52 ± 0.03a	3.04 ± 0.03b	108.27***
P (%)	0.312 ± 0.004c	0.347± 0.004b	0.450 ± 0.004a	0.345 ± 0.003b	516.67***
K (%)	1.49 ± 0.03c	1.81 ± 0.02b	2.43 ± 0.02a	1.41 ± 0.02c	871.72***
Fruit yield parameters					
Fruit weight (g)	6.68 ± 0.05c	6.94 ± 0.07c	7.52 ± 0.10a	7.24 ± 0.05b	52.01***
Fruit length (cm)	4.36 ± 0.03d	4.51 ± 0.04c	4.95 ± 0.05a	4.72 ± 0.03b	86.21***
Nº fruits plant $^{-1}$	26.42 ± 0.44c	26.35 ± 0.42c	31.52 ± 0.52a	27.18 ± 0.34b	64.07***
Fruit yield plant $^{-1}$(g)	176.60 ± 3.40c	182.97 ± 3.85c	236.96 ± 5.25a	196.76 ± 2.57b	97.06***
Fruit yield ton ha^{-1}	7.36 ± 0.14c	7.62 ± 0.16c	9.87 ± 0.22a	8.20 ± 0.11b	97.06***

Table S3. Effect of foliar SA applications on agronomic vegetative growth parameters as well as fruit yield-related attributes in the two different growing seasons (S1 and S2). The data are means ± SE from *n*= 30. Different letters in the same row indicate significant difference at P < 0.05 (Tukey's HSD post-hoc test). Results of one-way ANOVA test showing *F*-values and level of significance for selected yield parameters are also indicated. Level of significance: ***$P \leq 0.001$; NS = not significant.

Parameters/Season		SA treatments				*F*-values
		Control	1 mM	2 mM	4 mM	
Vegetative growth parameters						
Plant height (cm)	S1	87.35±0.63d	91.66±0.63c	102.33 ± 1.09a	95.41 ± 0.66b	66.75***
	S2	90.69±0.65d	95.82±0.57c	108.92 ± 1.08a	99.42 ± 0.66b	100.63***
Nº branches	S1	2.53 ± 0.09c	3.27 ± 0.08b	3.67 ± 0.09a	3.10 ± 0.10b	26.80***
	S2	2.53 ± 0.09c	3.20 ± 0.10b	3.87 ± 0.09a	3.33 ± 0.10b	34.43***
Stem girth (cm)	S1	2.32 ± 0.03a	2.30 ± 0.03a	2.28 ± 0.04a	2.27 ± 0.04a	0.48^{NS}
	S2	2.42 ± 0.03a	2.38 ± 0.03a	2.45 ± 0.02a	2.34 ± 0.02a	4.06^{NS}
Nº leaves	S1	36.57 ± 0.27d	39.73 ± 0.35c	51.17 ± 0.52a	43.83 ± 0.32b	279.31***
	S2	37.93 ± 0.33d	41.80 ± 0.35c	54.67 ± 0.56a	46.20 ± 0.32b	316.42***
Leaf area (cm^2)	S1	245.07±1.11b	245.83± 0.92b	250.27 ± 0.53a	245.73 ± 0.39b	9.05***
	S2	235.07±1.24b	237.37± 0.93b	243.93 ± 0.58a	238.23 ± 0.46b	19.23***
LRWC (%)	S1	76.16 ± 0.20c	77.62 ± 0.17b	81.87 ± 0.31a	78.45 ± 0.26b	102.07***
	S2	74.48 ± 0.21c	75.96 ± 0.16b	80.16 ± 0.31a	76.76 ± 0.27b	97.20***
MSI (%)	S1	73.01 ± 0.22c	75.17 ± 0.20b	87.27 ± 0.26a	73.01 ± 0.22c	905.23***
	S2	73.82 ± 0.25c	75.52 ± 0.20b	88.09 ± 0.22a	72.19 ± 0.20c	1066.03***
FVG (g)	S1	748.15±5.52d	812.94 ± 7.14c	1046.87±10.70a	896.83 ± 6.51b	279.31***
	S2	776.12±6.72d	855.23 ± 7.24c	1118.48±11.50a	945.25 ± 6.61b	316.42***
DVG (g)	S1	113.36±0.84d	123.17 ± 1.08c	158.62 ± 1.62a	138.88 ± 0.99b	279.31***
	S2	123.85±2.15d	132.54 ± 2.64c	167.04 ± 2.59a	139.36 ± 1.93b	63.36***
N (%)	S1	2.95 ± 0.03c	3.17 ± 0.04b	3.48 ± 0.03a	3.06 ± 0.03c	46.86***
	S2	2.97 ± 0.03c	3.21 ± 0.04b	3.56 ± 0.03a	3.02 ± 0.03c	62.58***
P (%)	S1	0.303±0.003c	0.333±0.003b	0.437± 0.003a	0.350 ± 0.004b	299.99***
	S2	0.325±0.003c	0.361± 0.003b	0.462 ± 0.003a	0.340 ± 0.003b	483.80***
K (%)	S1	1.54 ± 0.02c	1.83 ± 0.02b	2.38 ± 0.02a	1.42 ± 0.02c	408.26***
	S2	1.44 ± 0.02c	1.79 ± 0.03b	2.48 ± 0.02a	1.41 ± 0.01c	540.41***
Fruit yield parameters						
Fruit weight (g)	S1	6.60 ± 0.06c	6.88 ± 0.08c	7.54 ± 0.12a	7.30 ± 0.05b	23.58***
	S2	6.70 ± 0.04c	6.99 ± 0.06b	7.49 ± 0.08a	7.18 ± 0.05b	31.73***
Fruit length (cm)	S1	4.35 ± 0.04d	4.48 ± 0.05c	5.06 ± 0.05a	4.75 ± 0.04b	52.42***
	S2	4.36 ± 0.03d	4.54 ± 0.03c	4.84 ± 0.03a	4.69 ± 0.03b	86.21***
Nº fruits $plant^{-1}$	S1	25.20 ± 0.25c	25.33 ± 0.24c	30.67 ± 0.38a	26.83 ± 0.26b	78.42***
	S2	27.63 ± 0.49b	27.37 ± 0.48b	32.37 ± 0.60a	27.53 ± 0.40b	24.17***
Fruit yield $plant^{-1}$(g)	S1	167.89±2.10c	174.50 ± 2.98c	231.38 ± 4.94a	195.86 ± 2.7b	76.21***
	S2	185.30±3.72b	191.44 ± 4.04b	242.54 ± 5.43a	197.65 ± 2.87b	39.94***
Fruit yield ton ha^{-1}	S1	7.00 ± 0.09c	7.27 ± 0.12c	9.64 ± 0.21a	8.16 ± 0.09b	76.21***
	S2	7.72 ± 0.15c	7.98 ± 0.17b	10.11 ± 0.23a	8.24 ± 0.12b	39.94***

Table S4. Pearson's correlation coefficients among agronomic yield-associated traits. Statistical significance was represented as asterisks (*$P \leq 0.05$; **$P \leq 0.01$).

	PH	NoB	SG	NoL	LA	LRWC	MSI	FVG	DVG	N	P	K	NoFr/P	FrW	FrL	FrY/P	FrY t/ha
PH	1	.510**	0.107	.867**	.146*	.557**	.658**	.867**	.802**	.554**	.744**	.584**	.654**	.527**	.533**	.706**	.706**
NoB	.510**	1	-0.078	.584**	.252**	.418**	.486**	.584**	.535**	.491**	.569**	.517**	.363**	.378**	.424**	.434**	.434**
SG	0.107	-0.078	1	0.061	-.235**	-0.093	0.093	0.061	0.118	0.074	0.096	0.065	.187**	0.046	-0.075	.163*	.163*
NoL	.867**	.584**	0.061	1	.241**	.692**	.767**	1.000**	.932**	.655**	.844**	.694**	.671**	.595**	.657**	.753**	.753**
LA	.146*	.252**	-.235**	.241**	1	.490**	.328**	.241**	.200**	.240**	.292**	.369**	.127*	.151*	.253**	.168**	.168**
LRWC	.557**	.418**	-0.093	.692**	.490**	1	.751**	.692**	.608**	.573**	.697**	.656**	.405**	.471**	.555**	.503**	.503**
MSI	.658**	.486**	0.093	.767**	.328**	.751**	1	.767**	.729**	.731**	.890**	.914**	.634**	.448**	.527**	.667**	.667**
FVG	.867**	.584**	0.061	1.000**	.241**	.692**	.767**	1	.932**	.655**	.844**	.694**	.671**	.595**	.657**	.753**	.753**
DVG	.802**	.535**	0.118	.932**	.200**	.608**	.729**	.932**	1	.623**	.779**	.654**	.792**	.549**	.599**	.820**	.820**
N	.554**	.491**	0.074	.655**	.240**	.573**	.731**	.655**	.623**	1	.715**	.706**	.497**	.334**	.439**	.514**	.514**
P	.744**	.569**	0.096	.844**	.292**	.697**	.890**	.844**	.779**	.715**	1	.834**	.628**	.509**	.561**	.686**	.686**
K	.584**	.517**	0.065	.694**	.369**	.656**	.914**	.694**	.654**	.706**	.834**	1	.564**	.413**	.481**	.603**	.603**
NoFr/P	.654**	.363**	.187**	.671**	.127*	.405**	.634**	.671**	.792**	.497**	.628**	.564**	1	.413**	.418**	.913**	.913**
FrW	.527**	.378**	0.046	.595**	.151*	.471**	.448**	.595**	.549**	.334**	.509**	.413**	.413**	1	.764**	.745**	.745**
FrL	.533**	.424**	-0.075	.657**	.253**	.555**	.527**	.657**	.599**	.439**	.561**	.481**	.418**	.764**	1	.634**	.634**
FrY/P	.706**	.434**	.163*	.753**	.168**	.503**	.667**	.753**	.820**	.514**	.686**	.603**	.913**	.745**	.634**	1	1.000**
FrY t/ha	.706**	.434**	.163*	.753**	.168**	.503**	.667**	.753**	.820**	.514**	.686**	.603**	.913**	.745**	.634**	1.000**	1

Abbreviations: DVG, dry vegetative growth; FGV, fresh vegetative growth; FrL, fruit length; FrW, fruit weight, FrY t/ha, fruit yield tonnes per hectare; FrY/P, fruit yield per plant; LA, leaf area; LRWC, leaf relative water content; MSI; membrane stability index; NoB, number of branches; NoFr/P, number of fruit per plant; NoL, number of leaves; PH, plant height; SG, stem girth.